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# Validation and assimilation of satellite sea surface temperature to characterize sub-mesoscale features in assimilative ocean and coupled earth system prediction models

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2024 Ocean Predict Symposium
Paris, France



**18-24 November 2024**

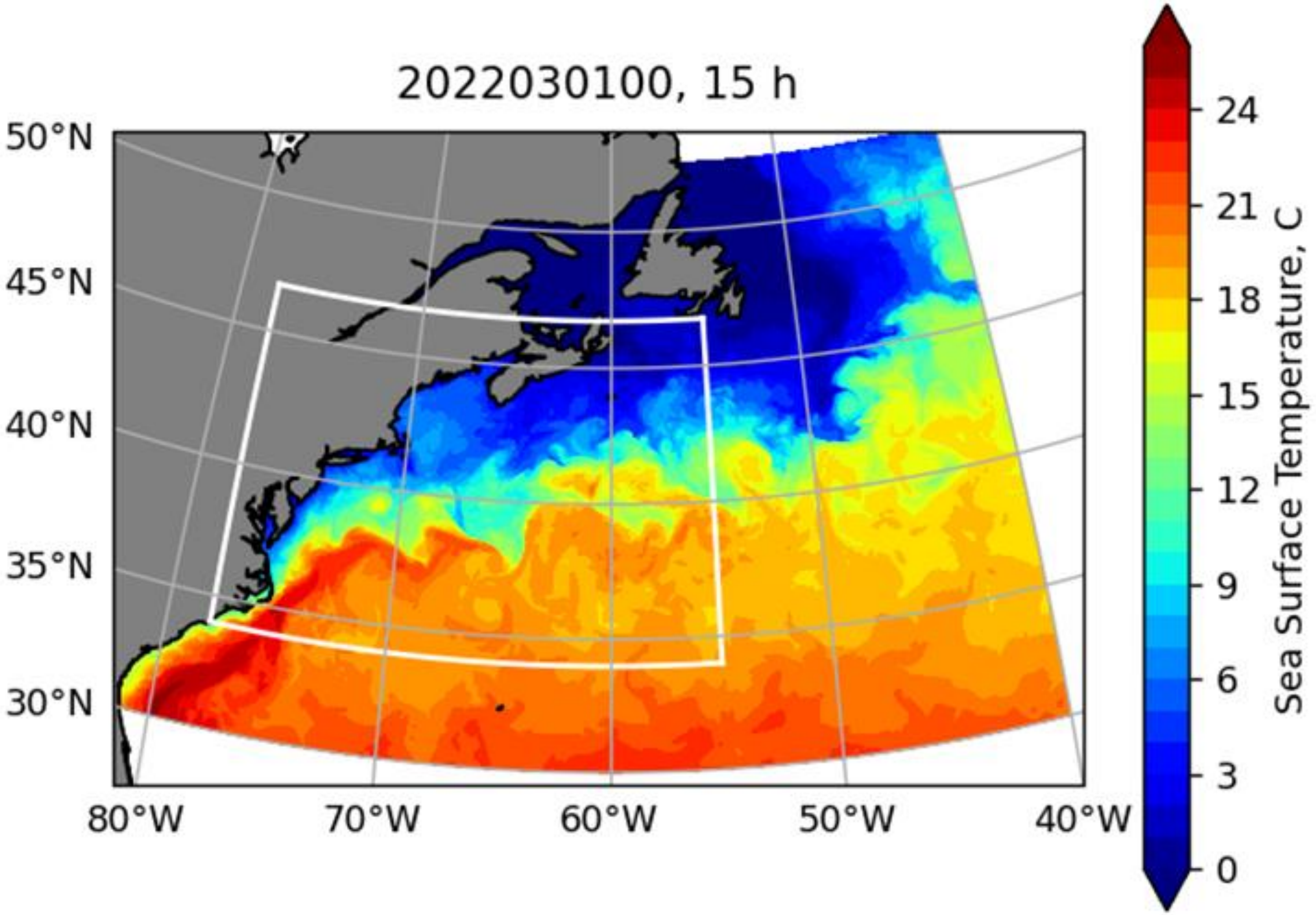
# Use of SST in assimilative ocean and coupled earth system prediction models

Sea Surface Temperature (SST) is an essential variable for Navy ocean forecasts.

- direct interest in temperature
- effects on sensor performance
- correlation with subsurface conditions
- heat flux between the ocean/atmosphere

Observations of SST are used to evaluate and correct ocean forecasts

What are the sources of the observations?



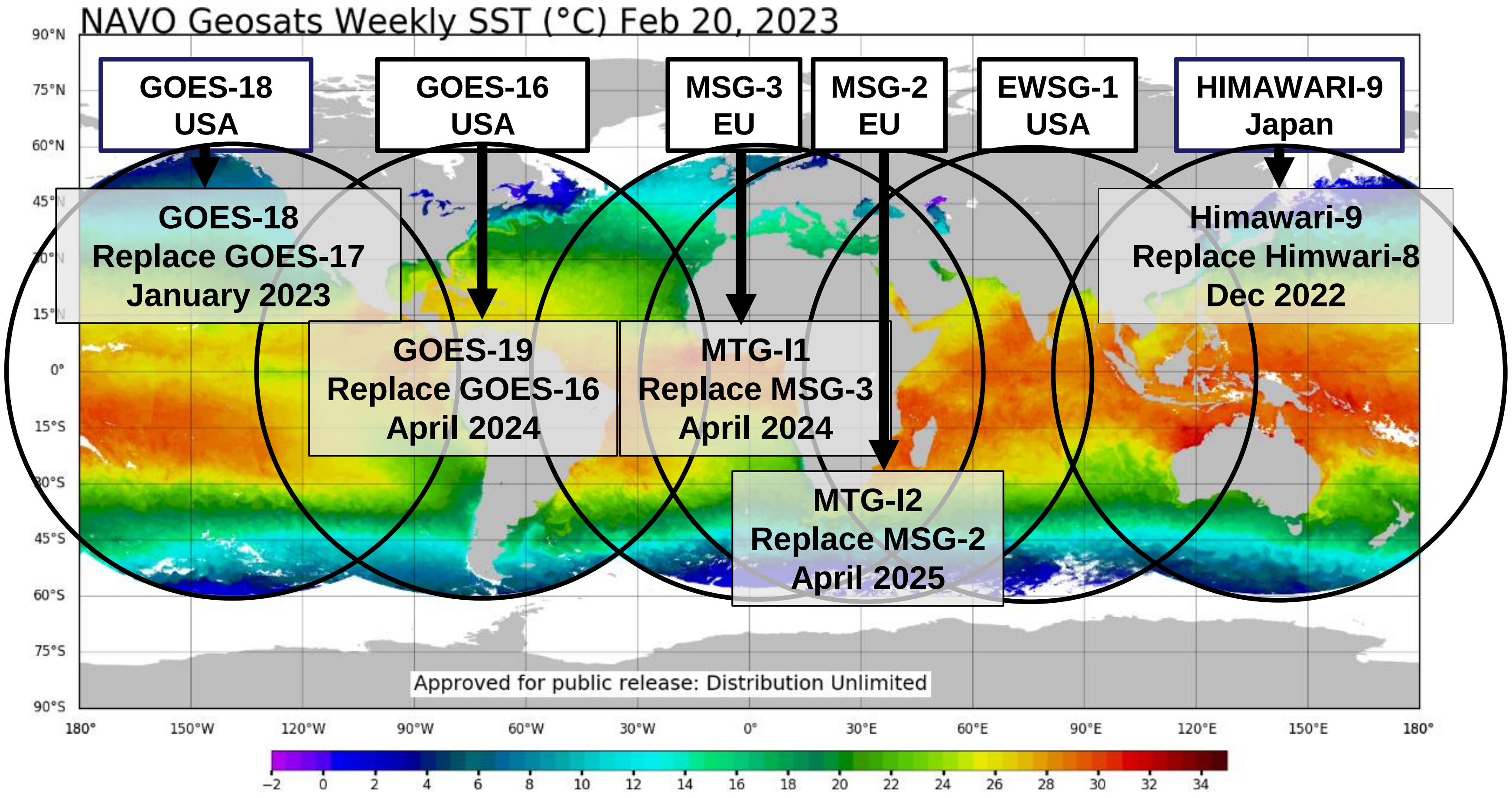
# Observation of SST: geostationary IR satellites

NAVOCEANO SST from geostationary IR satellites: GOES-16, GOES-18, Himawari-9; legacy EWSG-1

Geostationary IR SST weekly coverage map – support by multi-national GHRSST collaboration

Geostationary satellites use 2-3 IR channels to measure SST

Nadir footprint 2-4 km
SST refresh 10-60 min




Provide near-continuous global SST coverage except for polar regions; IR is obscured by clouds

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# Observation of SST: polar-orbiting IR satellites

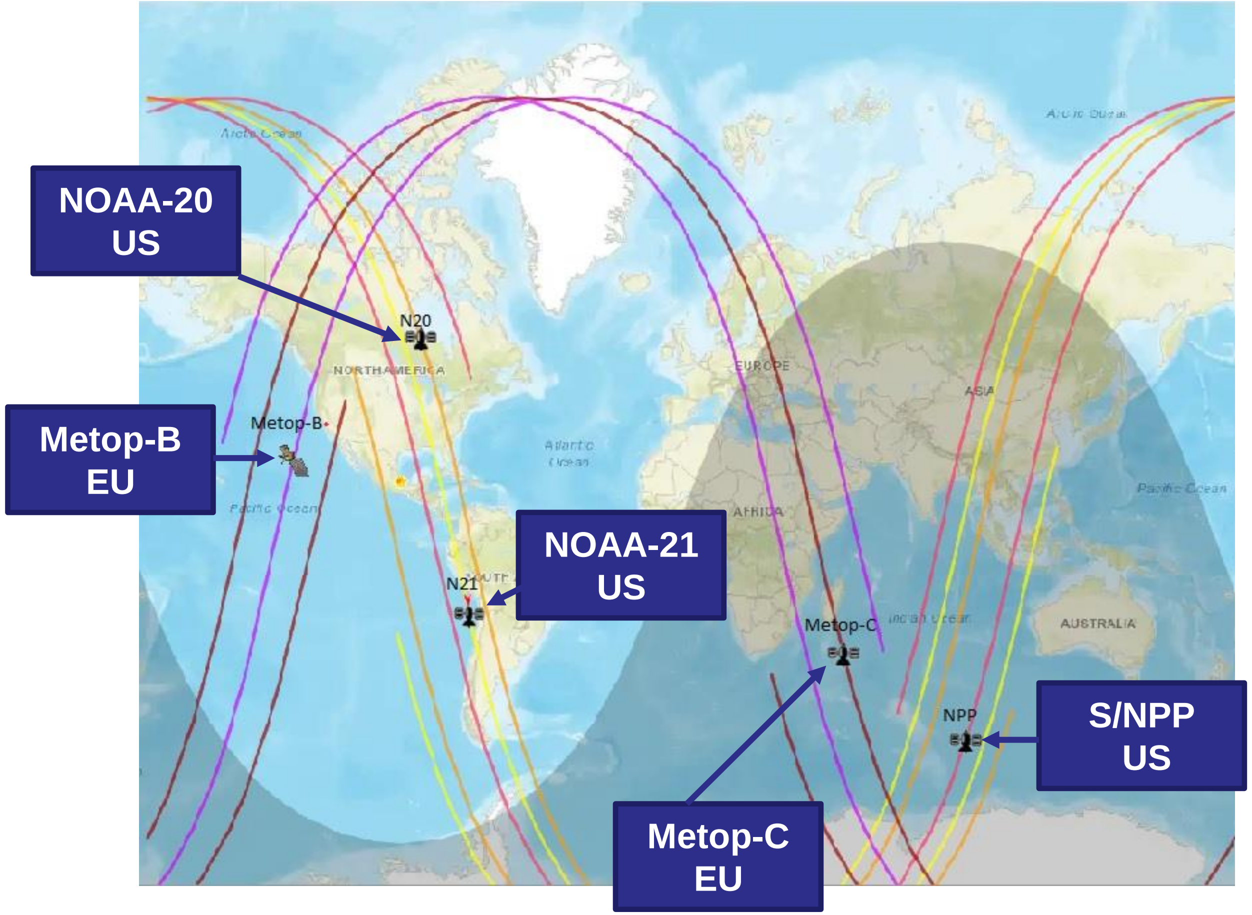
NAVOCEANO SST from polar-orbiting IR satellites: SNPP, NOAA-20 VIIRS; Metop-B, Metop-C AVHRR/3

Polar-orbiting IR SST orbits

Coverage supported by multi-national GHRSST collaboration

Polar-orbiting IR satellites use 2-3 IR channels to measure SST

Nadir footprint 750m-1km
SST refresh ~12 hours per satellite plus overlap

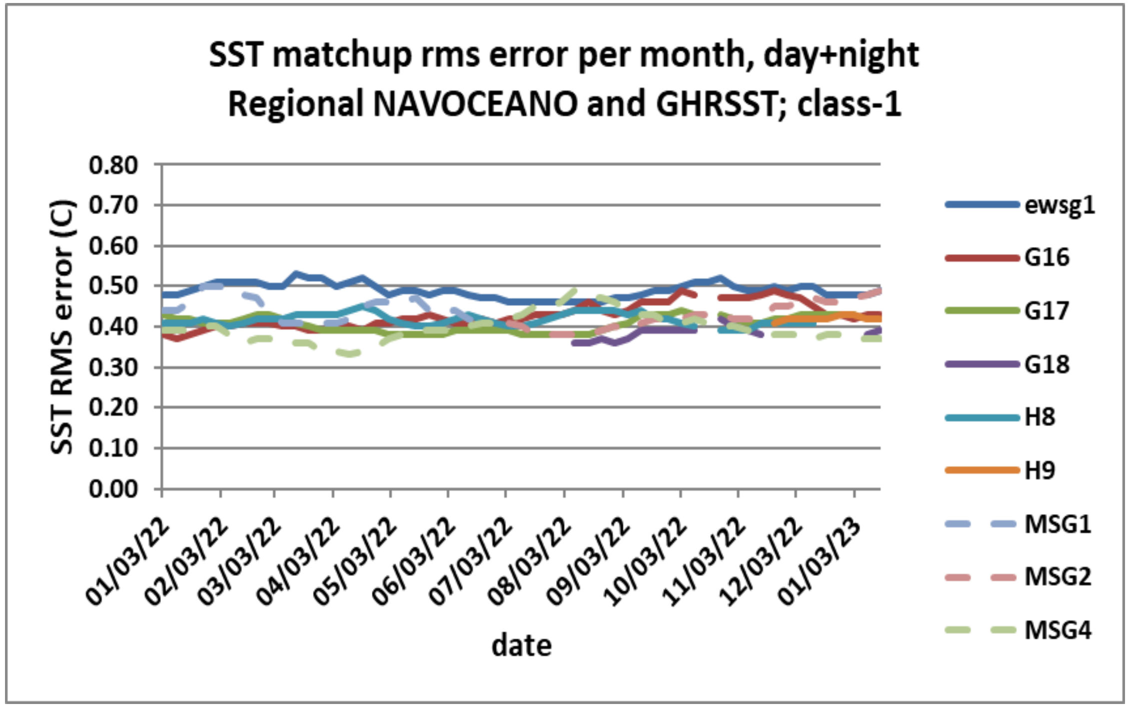



**Single-orbit combined orbit passes from 5 satellites:**

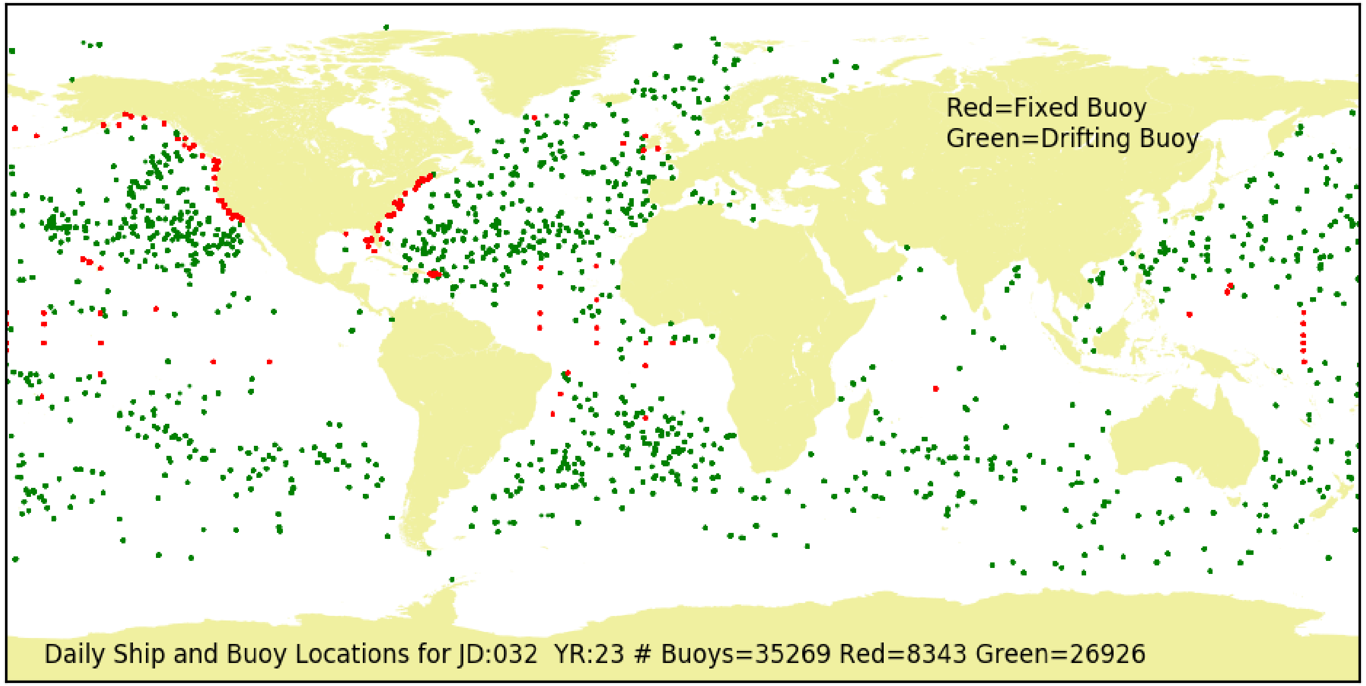
**S/NPP (US)**
**NOAA-20 (US)**
**NOAA-21 (US)**
**Metop-B (EU)**
**Metop-C (EU)**

Provide global SST coverage including polar regions; IR is obscured by clouds

# SST Retrievals: Validation relative to buoys




**Fixed and Drifting Buoys**




Monitors accuracy of geostationary satellite SST retrieval

# Observation of SST: ~6600 satellite SST observations per buoy SST

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Of the surface SST observations available for assimilation

- fixed buoys, drifting buoys
  - calibration and validation
  - assimilation may be locally important in cloudy, nearshore areas
- engine room intake, hull sensors, bucket SST
  - Insufficient accuracy unless from source specifically calibrated and maintained

|  | SST source | count | ratio to all buoys |
|---|---|---|---|
| buoy | drifting buoy | 29440 | 0.40 |
|  | fixed buoy | 43932 | 0.60 |
| satellite | all sat SST w/ H-9, G-18* | 485938840 | 6623 |
|  | AMSR-2 | 4804761 | 65 |
|  | EWS-G1 | 83191923 | 1134 |
|  | GOES-16 | 77084974 | 1051 |
|  | Metop-C | 20220513 | 276 |
|  | MSG-3 | 12271525 | 167 |
|  | Sentinel 3A+3B | 37670243 | 513 |
|  | S/NPP + NOAA 20 | 96524953 | 1316 |

These observations were available on 4 July 2023.
* estimated H-9, G-18 as = to G-16 for this brief

For every buoy SST observation there are ~6600 satellite SST observations

# 3DVAR variational data assimilation

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$$J(x) = (x - x_b)^T B^{-1}(x - x_b) + (y - Hx)^T R^{-1}(y - Hx)$$

$B$: background error covariance

$R$: observation error covariance

$x_b$: model state (background)

$y$: observation state

$H$: observation operator

$$\nabla_x J(x_a) = 0$$

3DVAR

$$x_a = x_b + (BH^T)(HBH^T + R)^{-1}(y - Hx_b)$$

$x_a$: called the analysis, the updated model field

$(y - Hx_b)$: called the innovation

$(BH^T)(HBH^T + R)^{-1}(y - Hx_b)$: called the increment

Variational data assimilation starts with a cost function.

We wish to minimize the cost function, such that any input state $x$ returns the least value.

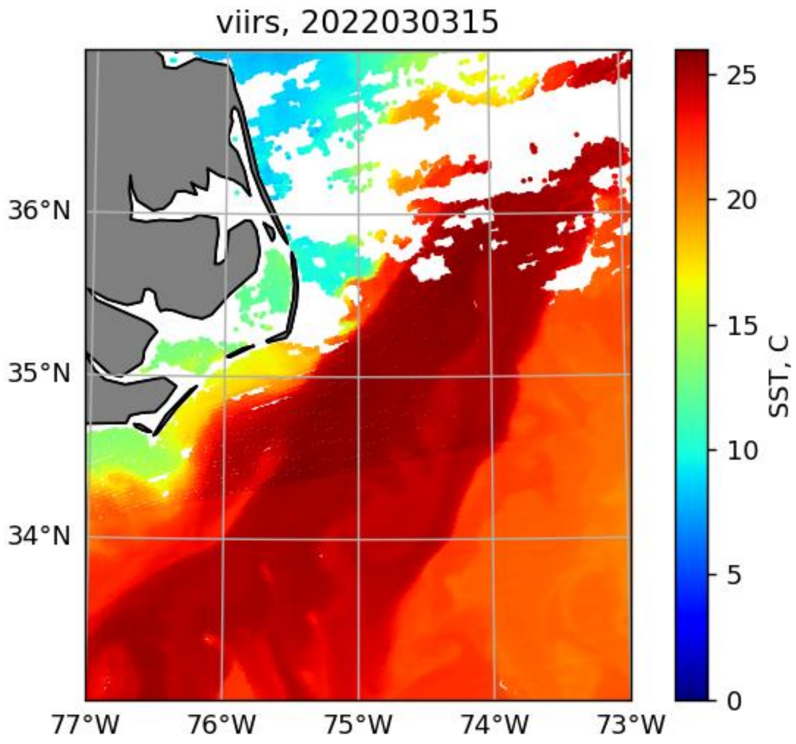
This minimization produces the formulation of data assimilation called 3D Variational data assimilation (3DVAR).

The inversion $(BH^T)(HBH^T + R)^{-1}$ can become ill conditioned when observation errors that are too correlated

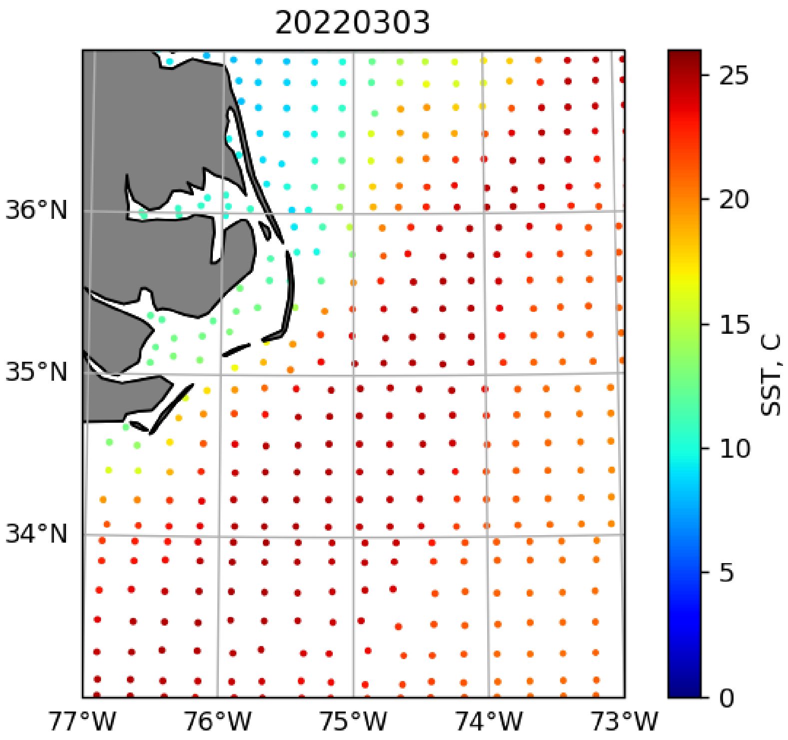
Present solution: Average data into **super observations** until the effective observation spacing is larger than the length scale in the error covariance

# SST Assimilation: present system using super observations

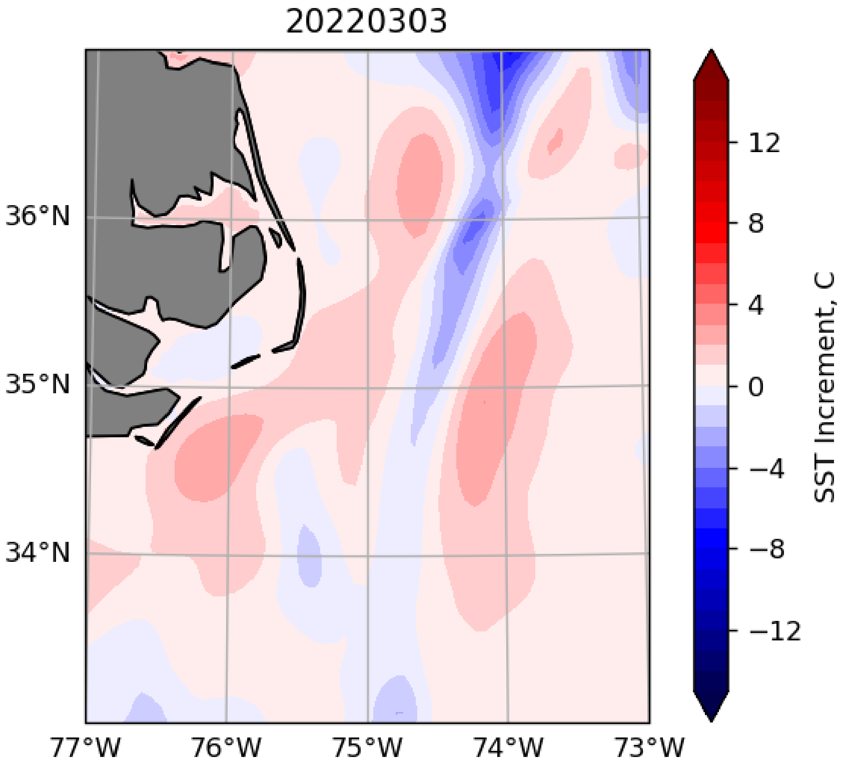
**Satellite SST**




**Super-ob SST**




**Assimilation Increment**



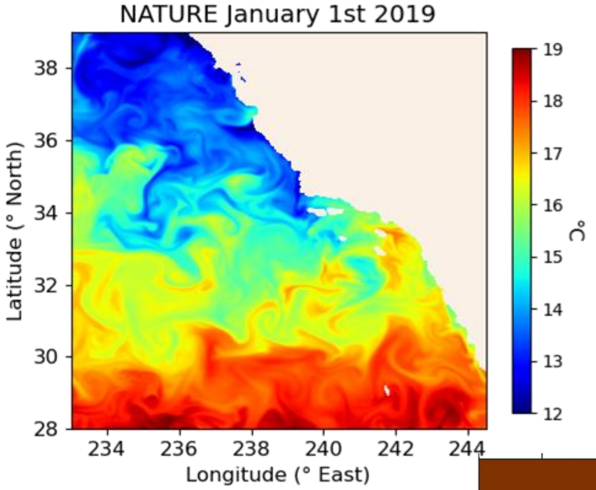

Fine scale information available for multi-scale DA

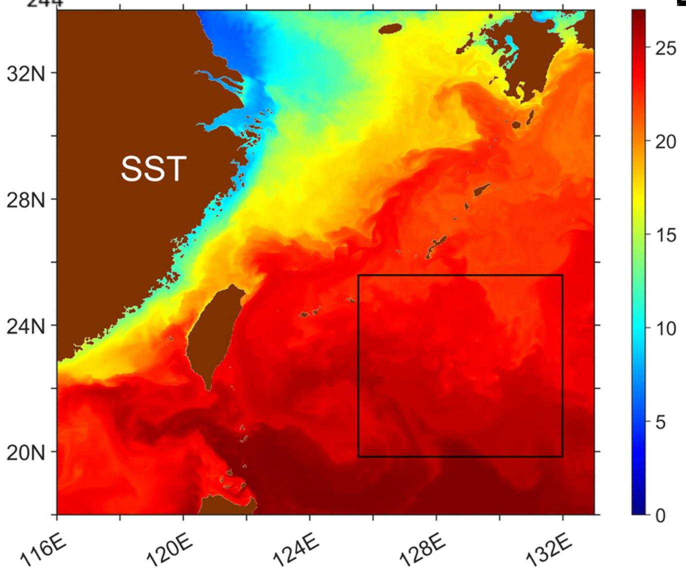
Fidelity is reduced by daily super-observation for consistency with DA length, time scales

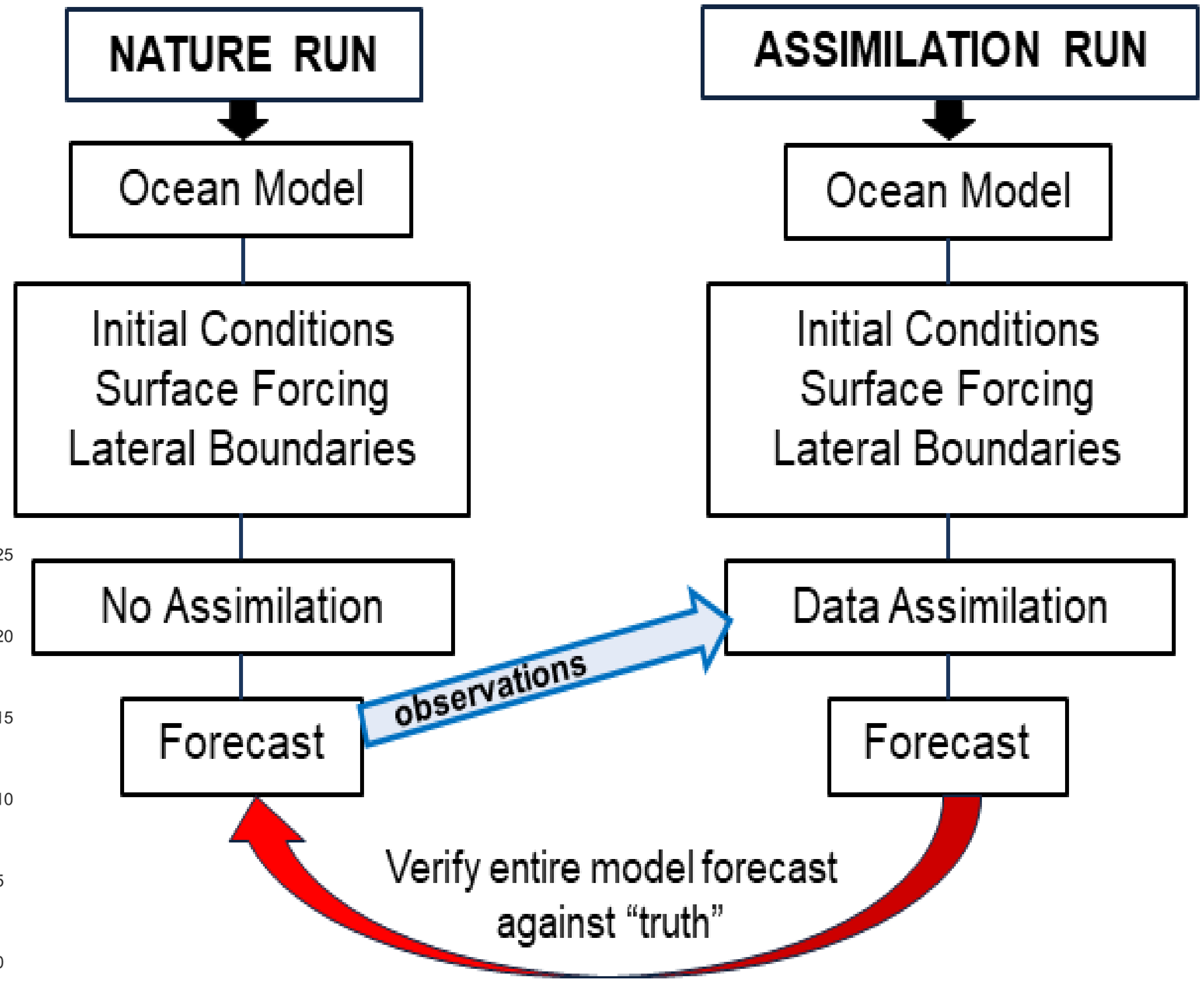
Present system drastically reduces original SST fidelity; work to better account for smaller-scales in space, time

# SST Assimilation: use OSSE to evaluate assimilation alternatives (complete sampling)

Observation System Simulation Experiment (OSSE) in East, West Pacific

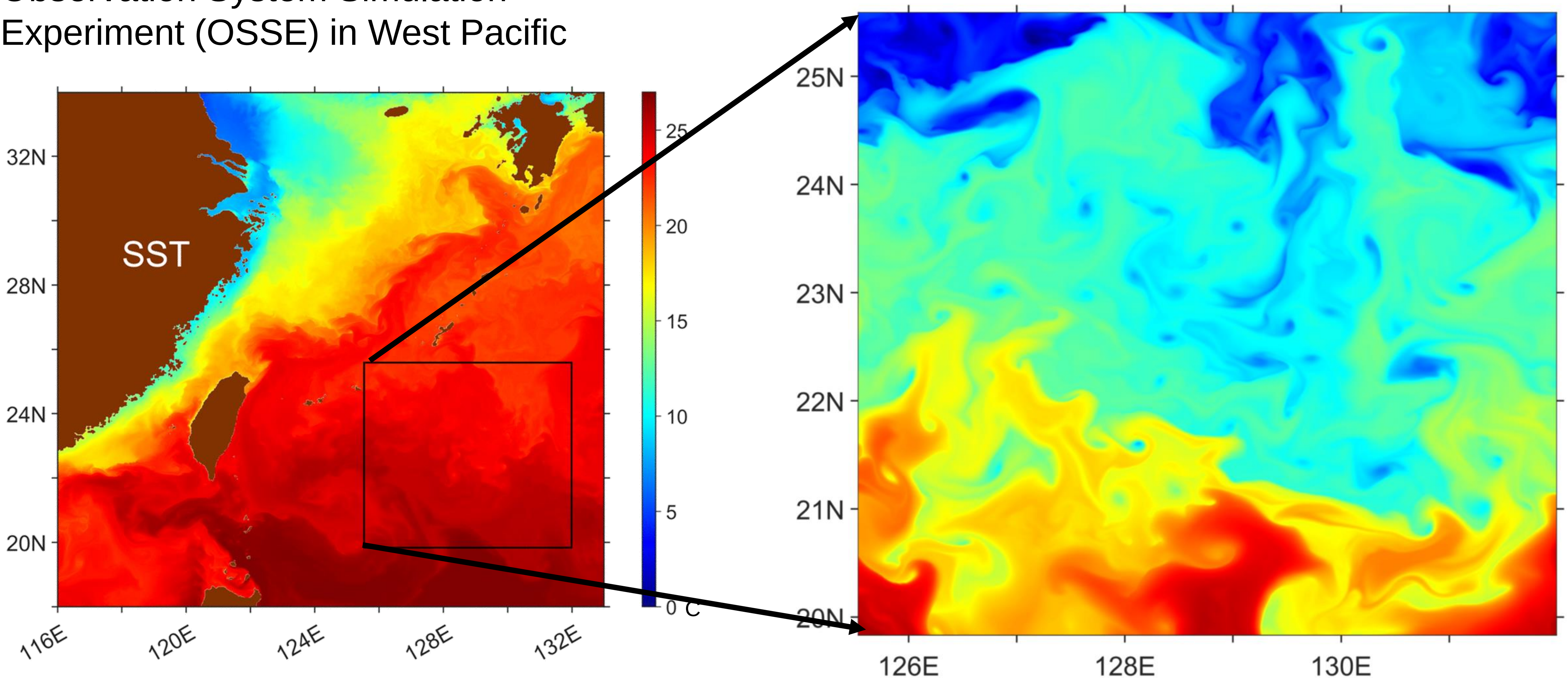


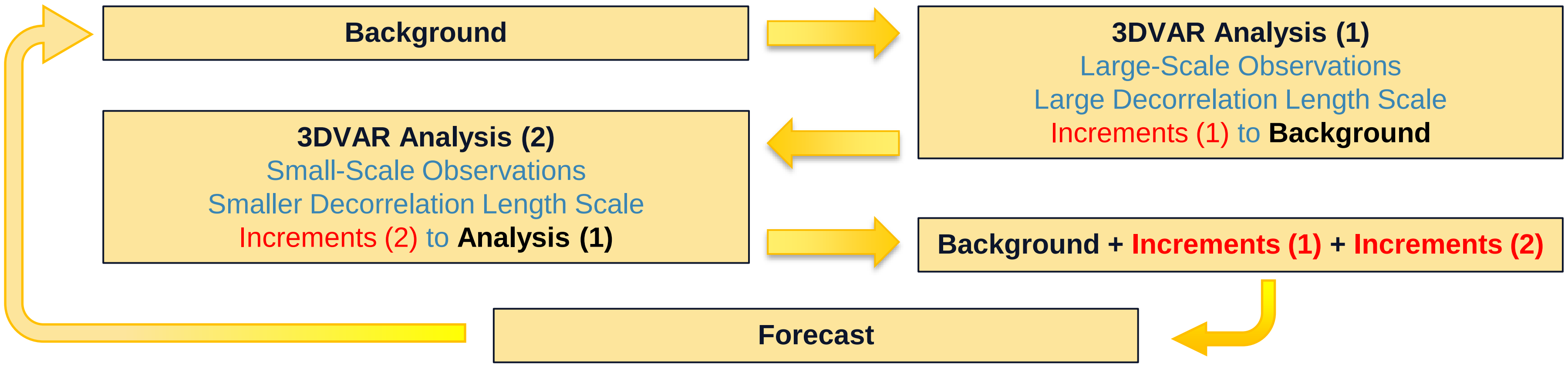



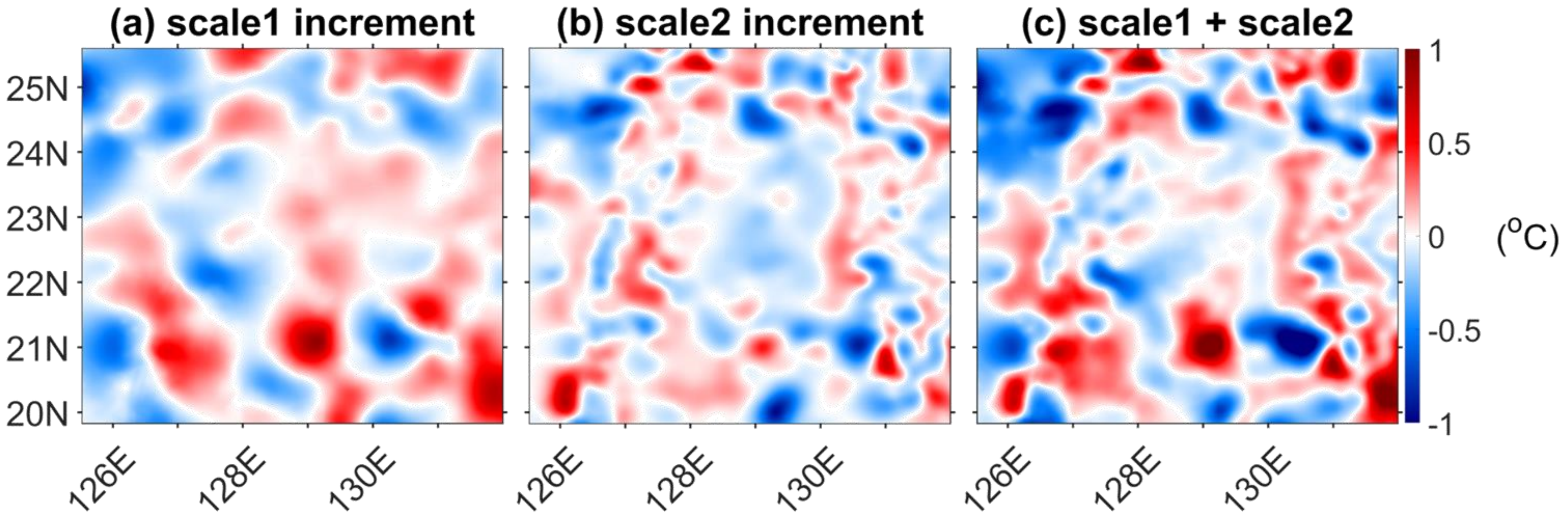
# SST assimilation: Subdomain to examine DA increments (update to background)

Observation System Simulation Experiment (OSSE) in West Pacific



# SST assimilation: Multiscale DA increments (correction added to forecast background)



# SST assimilation: Multiscale DA of SST offers clear benefit in the upper 100 m (see D'Addezio, Carrier, Souopgui, Iversen)

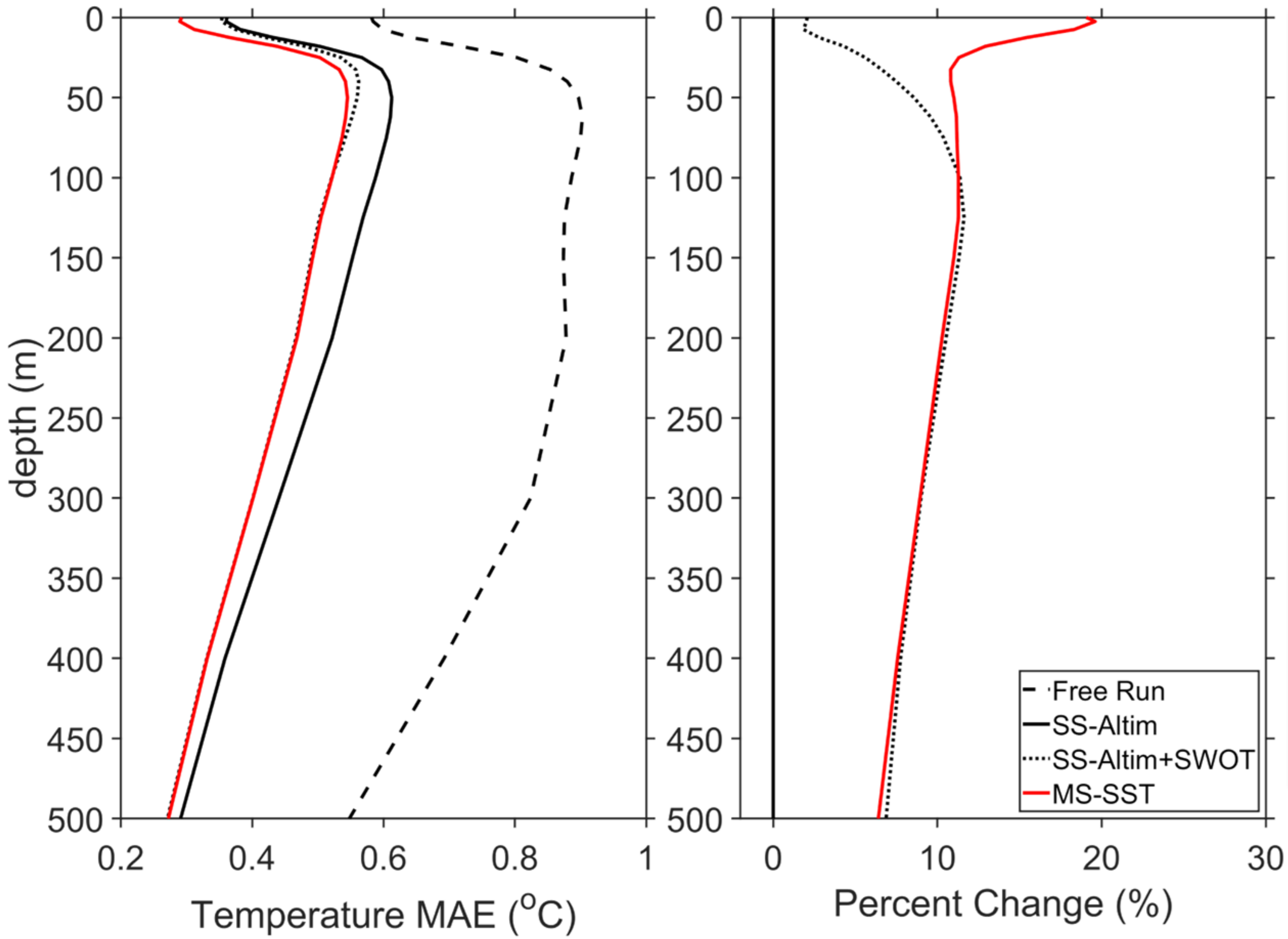
Evaluate error
(OSSE variant) – (Nature)
over whole domain
Jan. 1 - Jun. 30, 2016

OSSE variants:

- Free Run
- SS-Altim
- SS-Altim+SWOT
- Above + MS-SST

All variants but free run also assimilate SST in the single-scale step

SST is the only info source for the second step in multiscale




The figure on the right shows the additional % improvement beyond the standard single-scale assimilation of SST and nadir altimeter.

**Multiscale SST improves the analysis above 100 m**

# Use of SST in assimilative ocean and coupled earth system prediction models

Summary:

- Predicting Sea Surface Temperature (SST) is important for estimating near-surface and subsurface conditions, system performance, and forecasts of future air/sea conditions.

- Observations of SST are used to evaluate and correct ocean forecasts.

- Satellites provide the overwhelming majority of SST observations.

- Present operational assimilation methodologies combine these data into super-observations to avoid ill-conditioning due to correlated errors (too close in space).

- Small-scale information is lost in using super-observations.

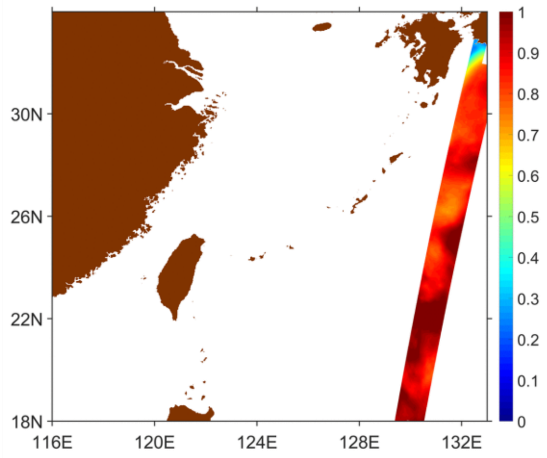
- New techniques are in development to better retain small-scale information
  - Multi-scale (D'Addezio, Carrier, Iversen)
  - Wavelet (Sciacca)

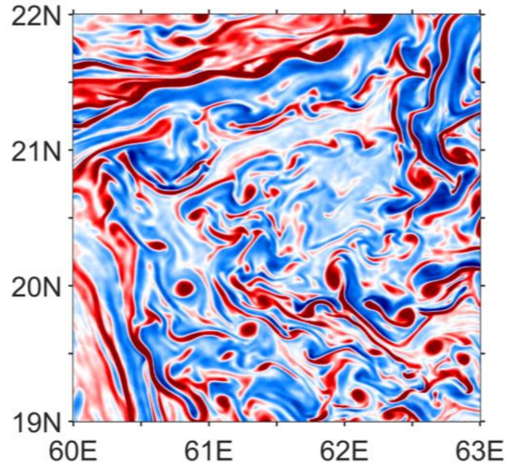
# Employment Opportunities

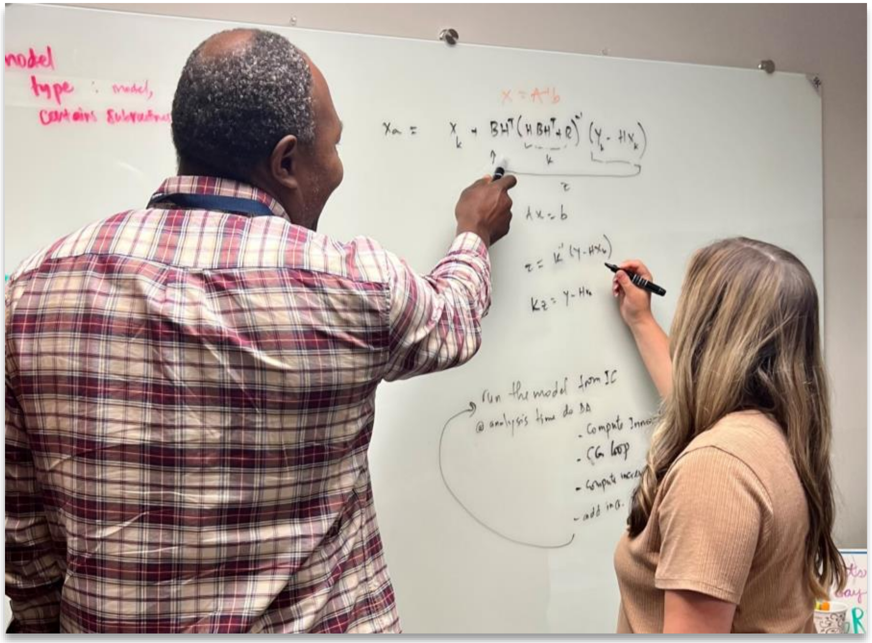
## Ocean Dynamics and Prediction Branch

### U.S. Naval Research Laboratory

### *Stennis Space Center, MS*



### Immediate Positions Available

- **Postdoctoral Fellowships** – Annual 2024 salary is $82,830. Renewable up to 3 years. *Benefits: Medical, Dental, Vision, Life*
- **Permanent Researchers** – Annual salary for full time federal civilian positions ranges from $80,000 to $150,000. *Benefits: Medical, Dental, Vision, Life, Pension, Retirement*
- Applicants must be a US citizen or US permanent residents at time of application
- Variable work schedules with partial telework options (No remote work)
- NRL is an equal opportunity employer

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